Renewable and Sustainable Energy Reviews 15 (2011) 4667–4672

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Can we close Earth's sustainability gap?

Ruud Weijermars *

Department of Geotechnology, Delft University of Technology, Stevinweg 1, Delft 2628CN, The Netherlands

A R T I C L E   I N F O

Article history:
Received 14 January 2011
Accepted 5 July 2011
Available online 29 September 2011

Keywords:
Ecological footprint
Sustainable energy solutions
Ecosystem services
Ecological dilemma matrix
Scenarios
Technophiles
Biophiles

A B S T R A C T

The principal options for engineering Earth's ecological future can be concisely visualized in a conceptual dilemma matrix. Scaling of the matrix with real world data confirms the widening of Earth's sustainability gap, due to our increasing ecological footprint. The simplicity of the dilemma matrix articulated here may help to focus the debate at future Global Summits and World Future Energy Summits on the critical scenario options. Geoscientists and engineers at energy companies share a major responsibility with many societal actors in setting the right example, particularly in searching for sustainable energy solutions. One view is that technology can help solve all issues. Another view is that nature is needed for sustainable ecosystem services. A most pessimistic view is based on analogy of human behavior with that of ants – eusocial groups like ourselves. Ant wars for access to limited resources warn us for a future where scarcity of resources may force us to resort to brutal, competitive behavior – rather than civilized diplomacy. Options to avoid such an outcome are outlined in this study.

Contents

1. Introduction

Five centuries of scientific inquiry and natural research, free from religious and other undue ideological censorship, have given us powerful concepts like Utopia [1], the Peak Population Theory [2], the Peak Oil Theory [3] and the Tragedy of Commons [4] (Fig. 1). These concepts urge us to think critically about our future world. We know well that Man's freedom and superiority to decide on the utilization of Earth's finite natural endowment may not necessarily be sustainable. A persistent disagreement on the sense of urgency to change our ecological footprint has prevailed at recent Global Earth Summits. Such disagreement impairs progress on common actions, and fundamentally is rooted in difficulties encountered in formulating a common vision for our future.

The necessity of political action to regulate the future use of our environment and natural resources first received major attention in the 1970s and 1980s. This was primarily due to the impact of studies by the Club of Rome [5] and the Brundtland Commission [6]. Over the past 20 years (1990s and 2000s), strong societal support for better management of our environment and natural resources [7] has resulted in public and private funding for major research programs.

Today, cause and effect of the competitive pressure between human population groups and the ensuing inequality in man's use of Earth's natural resources are better understood than ever before [8,9]. Our databases have become more reliable [10,11]. The anthropogenic impacts on the Earth's climate [12,13], on biodiversity [14–17], and on ecosystem services [18] are well documented. Man's ecological footprint is routinely monitored since 1999 [19]

* Tel.: +31 655 873 136.
E-mail address: R.Weijermars@TUDelft.nl

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doi:10.1016/j.rser.2011.07.085

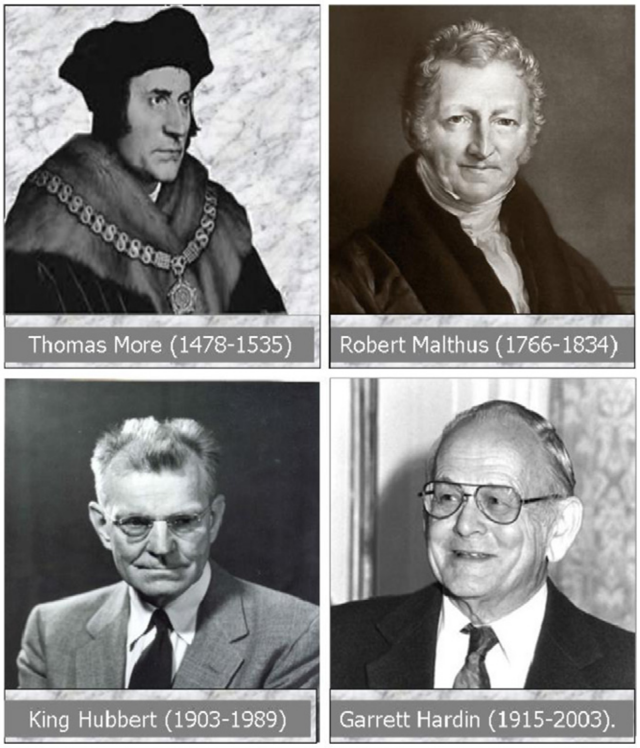


Fig. 1. Founding fathers who provided a theoretical basis for critical inquiry into our future [1] accounting for the finitude of Earth's natural resources [2–4].

– a global benchmark is published every 2 years, since 2000 [20].

Further, ambitious Earth Summits and World Future Energy Summits will be held, aimed at making better choices for our future. For example, the upcoming 2012 Rio de Janeiro Summit will be dedicated to vision sharing, cooperation and transformation, focused on sustainable development in a green economy. The discourse on our options and choices for preserving future value of our environment remains important for humanity's future prospects. This article juxtaposes two viewpoints at each end of the sustainability spectrum, and introduces a dilemma matrix that can serve as a roadmap for highlighting the principal scenarios for Earth's ecological future. The matrix also visualizes the growing sustainability gap.

2. Energy extraction impacts

Geoscientists and engineers involved with mineral and petroleum extraction must act responsibly; professional conduct by companies and individuals includes the avoidance of undue impact on the natural environment [21,22]. When it comes to energy, the term sustainability is commonly used in two ways: (1) sustainable energy often means a focus on renewable energy sources as opposed to depletable fossil and nuclear resources; (2) sustainable energy may also be interpreted in a more holistic sense, such as to include energy resources that do not adversely impact the environment. Lately, the first meaning is more widely supported, the second less so.

The risk of adverse surface footprint by energy extraction operations is considerable, and remediation is not always done or possible. Fig. 2a and b shows two surface impacts from oil and gas extraction on fragile ecosystems: Louisianan salt marshes (US) and Siberian tundra (Russia). Neither of these past track patterns can be remediated; each subsequent digging or covering of tracks would further alter an already disturbed ecosystem. Access roads for shale gas wells provide another adverse footprint impact (Fig. 2c); on-shore wind farms, sometimes even placed inside natural reservations as eco-friendly energy solutions, have a surface footprint (Fig. 2d) rather similar to gas production sites.

It is fair to hold mineral and energy engineering firms and individuals responsible for any adverse environmental impact of their operations. However, city planners, infrastructure developers and farm 'factories' bear a similar responsibility. Recent estimates state that about half of our planet's land surface has been modified by anthropogenic activity [23]. One study called the current geological era the *Polluticum* [24]; another study calls it the *Anthropocene* [25]. Evidence is mounting that past and present destruction of natural ecosystem services has now become so large that these require additional expenditure from future generations: to replace natural services corrupted by anthropogenic activity. The next section briefly outlines these cost estimates and the article then proceeds to address the scenarios for future options and choices.

3. Cost of ecosystem damage

We have reason to heed the financial consequences of anthropogenic changes to our environment. Recent studies [17,18] emphasize that the result of degrading and destructed ecosystems goes further than accelerating global warming and the loss of biodiversity. Loss of ecosystems also means a reduction in natural buffers and biogenic processes that regulate the quality of our food resources; examples are: natural purification and replenishment of drinking water, natural pollination of our crops, and natural pest control agents. The degradation of our ecosystem has been calculated to cost the world's economy around 50 billion Euros per year [26]. This sum is the extra cost we have to incur to replace the loss of natural ecosystem services. By 2050, the opportunity cost for not having preserved biodiversity and ecosystems at year 2000 levels will have lead to an additional cost of 14 trillion Euro, equivalent to 7% loss in global GDP in 2050 [26].

The principal drivers for an increased anthropogenic pressure on our environment are the global growth in population, economic activity, energy consumption, and food production. Normative energy mix scenario studies by the OECD/IEA [27,28] calculate the cost of executing detailed future energy scenarios that can reduce GHG emissions to 50% of 2005 levels to amount to USD 1.1 trillion per year (equivalent to Italy's current GDP or 1.1.% of global GDP each year) from now until 2050. This sum is needed to establish a cleaner global energy mix by a combination of shift in primary energy sources as well as innovation in energy technology.

4. Two principal viewpoints

The implementation of normative energy scenarios and the conservation of ecosystem services require collective agreement on actions and acceptance of their cost. The debate on the need to preserve our planetary state continues [7–11,29,30]; unanimity on the sense of urgency has not yet been reached. Biophiles and technophiles represent two main groups [31], each with their own vision for our future. Biophiles emphasize that humans need nature for replenishment. In their view, overexpansion of our settlements is harmful to Earth, and sustainable living is seen as a necessity for our survival as a species. Technophiles think that Earth can be further engineered and technology solutions can always be found for our future survival, even when ecosystem services decline. They commonly find the preservation of natural ecosystems less important and think that the cost of natural preservation may be too high. Biophiles warn that the deferred cost due to unsustainable engineering impacts on our environment will be even higher.

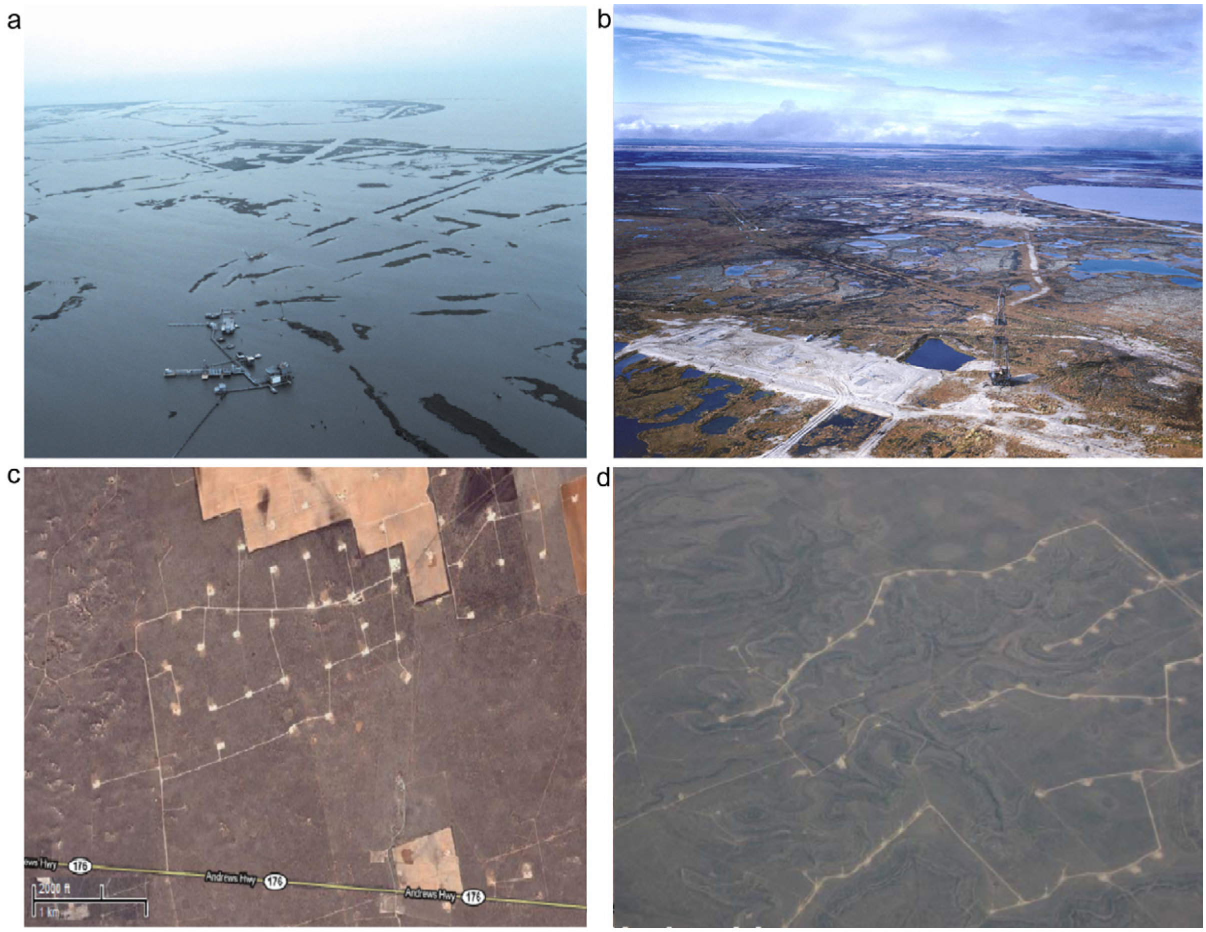


Fig. 2. (a) Straight lines in submerged salt marshes of Southern Louisiana are dredging channels made to float oil rigs into the marshes for oil extraction (courtesy Louisiana Department of Wildlife and Fisheries). (b) Access roads and drilling mud pits in the Urengoy Field is Russia's largest gas field (courtesy Nord Stream AG). (c, d) Access roads for shale gas wells and wind farm in Texas, US (courtesy Google Earth).

A third, major group of people is comprised the general public, including shoulder-shrugging citizens. This group is commonly less interested in a systematic discussion and less familiar with the rules of scientific inquiry. Their views are in part opiniated by the media, which translate to them the progress and outcomes of the discourse between biophiles and technophiles. Final policy choices for our future must be supported by our politicians and their constituency. The roles of the general public and the media therefore are enormously important in the decision-making process. A leading factor in the final policy choices of many nations, it is assumed here, remains the outcome of the debate between biophiles and technophiles. The media, politicians and general public are eager to hear solutions, which means biophiles and technophiles must settle their differences and reconcile their views, rather sooner than later.

5. Ecological dilemma matrix

The disparate views held by biophiles and technophiles are, in practice, separated by gliding scales that can be concisely graphed in a dilemma matrix (based on a generic dilemma management concept [32]), as shown in Fig. 3. The dilemma matrix distinguishes four quadrants, which provide a concise framework for bringing more transparency in discussions aimed at developing a common global vision for our planet's desired future.

The upper left quadrant is favored by societal groups and individuals with preferences for technology oriented solutions; they rely firmly on future engineering to solve our societal needs. The increasing ecological footprint is commonly accepted by them as an additional burden. Pre-emptive environmental engineering (reducing GHG emissions; climate control, ecological footprint reduction) to preserve a natural status quo is not a major priority for them.

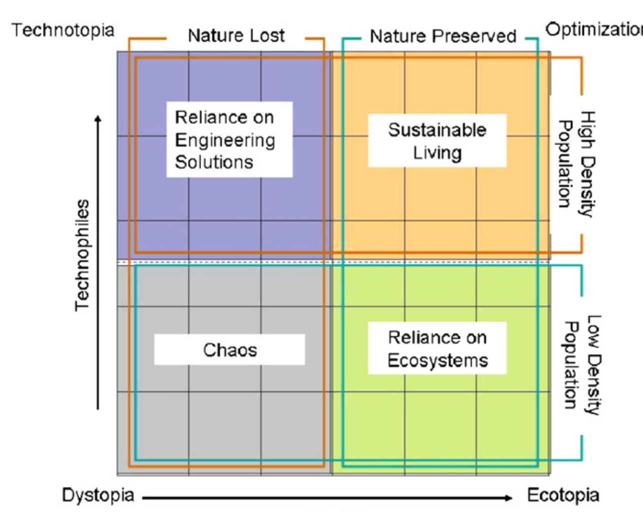


Fig. 3. Dilemma matrix reconciling the viewpoints of biophiles and technophiles to arrive at optimum solutions for sustainable living.

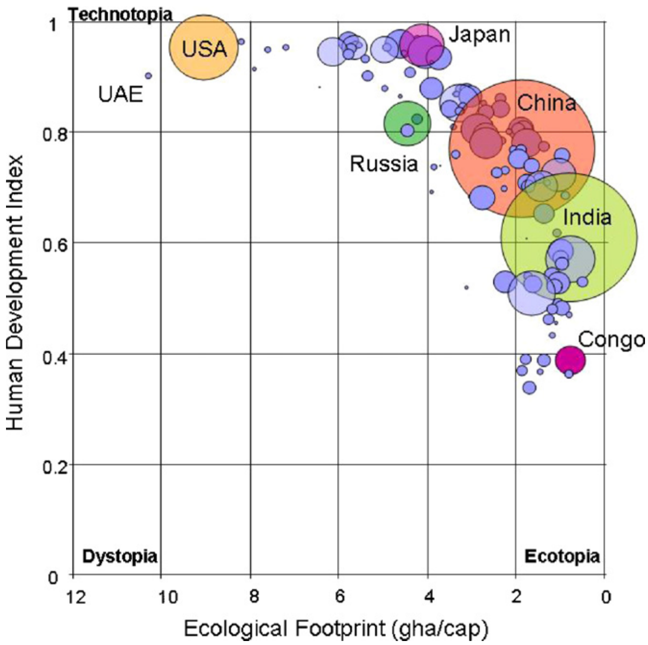


Fig. 4. Dilemma solution matrix for 125 representative Earth nations. Bubbles are scaled for relative population size. India and China are accelerating their increase in ecological footprint (global hectares per capita) – and their magnitude matters. Data from UNDP [35] and Global Footprint Network [36].

The lower right quadrant is favored by biophiles, who commonly find that man's technocratic engineering solutions should have no net negative impact on our planet. According to them, we should strive to preserve Earth's natural state and accept the payment of penalties and remediation costs for its conservation.

Sustainable living, upper right quadrant, requires a compromise between the two extreme views of pure biophiles and pure technophiles. Our relatively high population pressure needs engineering solutions for many commodity supplies, but in balance with the environment by accepting the additional cost for mitigating undue pollution and remediate any destruction of the commons.

The lower left quadrant represents a situation where neither engineering solutions nor natural ecosystems can satisfy our basic human needs. This is dystopia, the result of a failed human experiment with nature; population numbers will decline and many Earth regions will be abandoned and left uncultivated. The recovery and emergence of new natural ecosystems, with sufficient biodiversity for sustainable living in these abandoned regions, may take thousands to millions of years.

6. Scaling the dilemma matrix

Each country makes choices about its strategy for economic growth, energy mix, and industrial and services technology development. The resulting combination of technology reliance and ecosystem reliance is at anyone time (in the present and future) the outcome of past choices and a complex decision-making process of the stakeholders [33,34]. Fig. 4 plots a scaled version of the technotopia–ecotopia dilemma matrix, using the human development index as a proxy for the technology reliance, and the ecological footprint as an inverse measure for the reliance on natural ecosystems. A clear trend emerges: nations migrate upward in the plot away from the ecotopia quadrant into the technotopia quadrant. Similar maps of Earth nations' reliance on engineering solutions versus reliance on ecosystems show that our planet is now predominantly a technocratic society with an ever increasing ecological footprint [37].

Detailed assessments by the Global Footprint Network [38] show that mankind jointly uses more of the Earth's carrying capacity than can be sustained by its natural capacity. The excess use is termed ecological overshoot, and the cross-over point occurred in the 1970s. Ecological overshoot means [39] the available ecosystem per capita is not capable-with current technology-to provide the resources needed and absorb the carbon dioxide generated. In 2006, Earth population's total ecological footprint had attained 44% overshoot [36,38], meaning 1.44 times the actual Earth surface would be needed as a minimum to sustain our current use. The annual growth of ecological overshoot implies that Earth cannot sustain its current population for much longer if the current trend toward technotopia continues.

7. Scenarios for our future

Fig. 5 portrays the primary trend toward technotopia that man has taken, supported by the industrial and technology revolution of the 19th and 20th Century. Unless new technologies provide affordable and durable solutions that help to unburden the commons, the sustainability gap between technotopia and sustainable living will continue to grow wider (path 1 in Fig. 5), and our ecological footprint will burden heavier on the planet. A continuation of the present trend toward technotopia is not considered sustainable, based on our current state of technology and knowledge, as pointed out in numerous earlier studies [8–11].

Two major scenarios are possible for the long-term future (50 years +). An optimistic scenario (path 2 in Fig. 5) reverses the technotopian trend, back toward sustainable living. The establishment of sustainable living has succeeded with the support of ecosys-

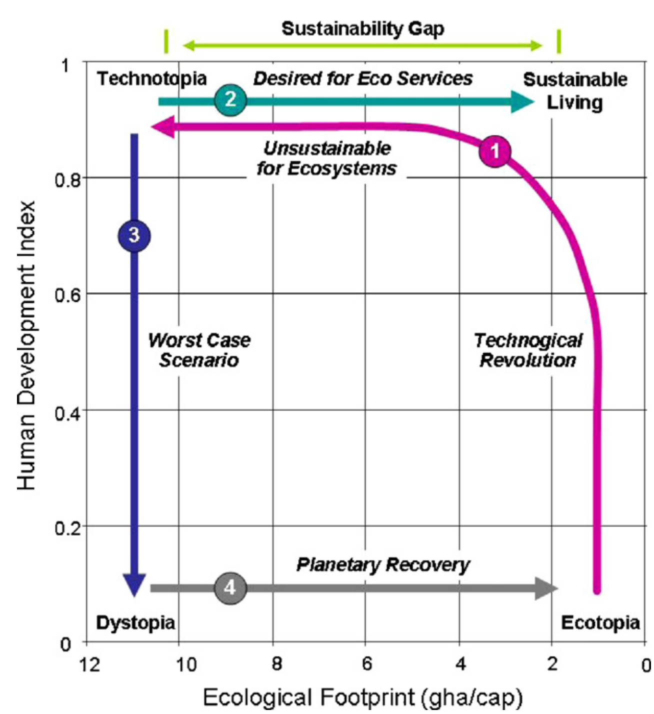


Fig. 5. Current technotopian trend toward our future (red arrow, path 1) and possible scenario alternatives: an optimistic scenario (green arrow, path 2) requires action to close the sustainability gap; a pessimistic, worst case scenario (blue arrow, path 3) envisions a decline of our civilization, due to a limited capacity to engineer solutions in depleting ecosystems with increased scarcity of natural resources. The result of this scenario may be dystopia, followed by a slow planetary recovery (grey arrow, Path 4). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

tem services and an effective closure of the sustainability gap. This scenario will require that man accepts the higher cost of all anthropogenic activities that interfere with nature, to unburden the commons and to reduce any net impact on the environment, so ecosystems can recover. The required cost rises may be hugely unpopular politically, but are necessary to avoid the higher cost of a worst case scenario.

In the pessimistic, worst case scenario (path 3 in Fig. 5), technology engineering is no longer capable to provide integrated solutions, due lack of resources. Chaos starts to prevail in our society, and ecological footprints remain large (or even grow) as our scramble for the last resources continues. Our reluctance to bear the cost of remediating polluted commons and persistent inaction against the further degradation of our environment ultimately leads to a decrease in the human development index. Human population numbers start to decline, due to progressive depletion of adequate resources (food, water, and energy).

A slow planetary recovery can only begin after a dystopian correction of our overpopulating human species (path 4 in Fig. 5): vast land areas will no longer be used by us. At best, we will have retracted to certain geographical sites to establish local societies with a new order.

8. Human analogy to ant wars

An optimistic scenario highlighted in the dilemma matrix proposes to reduce ecological overshoot by closing the sustainability gap. Sustainable living is thereby achievable, but requires prudent action against the further degradation of our planet's eco services. In the pessimistic scenario, our future may well be similar to that seen in past futures of ant colonies. Wilson [40,41] extended evolutionary theory to social organizations or eusocial groups (insects: ants, termites, and bees): their population biology is highly competitive and led by survival of the fittest; weaker ant colonies subside to extinction. Such groups colonize, kill and exploit, while functioning according to a well structured hierarchy and a set of behavioral rules. Ant wars and outcomes of invasion from powerful ant groups [40,41] are as devastating as Diamond [42] showed past human wars to be for the weaker and less well equipped human groups. In fact, humans can be considered more ruthless than Wilson's eusocial groups, because our behavior is characterized by a HIPPO strategy: habitat destruction, invasive species behavior, pollution, population expansion and overharvesting (overfishing) – the oceans are left unspoiled by ants, but not by us.

9. Discussion and conclusions

This article is titled: "Can <u>we</u> close Earth's Sustainability Gap?", underlining that each of us shares an individual and joint responsibility for our home planet's future. Studies continue to probe why human nature is predisposed to denial of misconduct; and why humans accept only limited stewardship of Earth and the life it harbors [43]. An overview of cognitive dissonance of the modern world about its future prospects for sustainable living was recently published by William Rees [44]. Much of the blame is laid on an ecological behavior focused on short-term economic benefits (i.e. *Homo economicus*).

Evidence is widely accepted, even by social scientists [11,23], that man has become a geophysical force and is interacting in an unprecedented way with natural forces in shaping Earth's future. Efforts to preserve a pristine ecosystem and biodiversity conservation have already failed in many locations on Earth [45]. A possible conclusion is that technophiles have had more impact on our current societal choices than biophiles. Consequently, biophiles must find better ways to convince technophiles and other skeptics of the sense of urgency to move toward sustainable solutions – otherwise the sustainability gap will only widen.

Ultimately, the outcome of this debate may be a fierce fight for access to control over the remaining resources just like ants do: death and brutal, competitive behavior will then prevail, rather than civilized diplomacy. Until that stage has been reached there is still time for us to act and avoid this pessimistic scenario. Global Summits play a pivotal role in finding ways to settle on a common vision in order to ensure that sustainable living becomes a real option for the near – rather than remote – future. A heightened sense of urgency commonly accelerates the debate toward the critical actions [46,47]. The dilemma matrix and sustainability gap articulated in this article may help the change process. We would be wise to opt for the optimistic rather than pessimistic scenario, and act accordingly.

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